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Head Mounted Displays

Analyses of Current Technologies and Future Applications

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13. ABSTRACT (*Maximum 200 words*)

This document provides a top level analysis of Head Mounted Display (HMD) systems for new missions or functions. It provides a collection of data and objective assessment on HMD technology and analyzes evolving HMD technologies that may be incorporated into technology demonstrations. This report will aid DoD components in the assessment, evaluation and qualification of HMD technology as it may be applied to meet established or future requirements for force capabilities.

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To: Pat Mawby

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1. HMD Overview

Head mounted displays have been used worldwide for almost 30 years in over 10,000 aircraft. Helmet-mounted displays exist in less than 500 aircraft, most of which are helicopters.

The use of HMD's for simulation and training purposes is an enigma. Researchers and developers over the years have battled with the technical and human factors issues that confront them constantly.

Currently, the most popular choice for displays are ***liquid crystal displays*** **or (LCD's)**. Some high end HMDs use ***cathode ray tubes*** **(CRT's)** for the display.

Purpose of this Report:

The use of advanced visuals technology such as HMDs is becoming increasingly important as soldiers are required to carry out far more complex mission-oriented tasks on the battlefield of the future.

SOAR Investigative Aims-

- To provide a broad yet simplistic overview of HMD systems using a survey of available data, examination of memos, and a series of market reports.

SOAR Parameters

This SOAR provides a top level analyses of HMD systems for new missions or functions. It is the intent of this SOAR to provide a collection and objective assessment of HMD technology and to carefully analyze evolving HMD technology that may be incorporated into technology demonstrations. The broad purpose of this SOAR is to aid DoD components in the assessment, evaluation, and qualification of HMD technology as it may be applied to meet established or future requirements for force capabilities or to assess the ability of individual systems or aggregations of system, people, and institutions to meet such requirements.

This report also focuses on the trade-off between control and display complexity and overall system integration, areas being addressed by emerging HMD technologies.

2. Definitions

1) *Head Coupled*: Displays or robotic actions that are activated by head motion through a head tracking device.

2) *Head Mounted Displays*: A set of goggles or a helmet with tiny monitors in front of each eye which generate 3 dimensional (3D) images. The HMD provides the primary visual input for the individual say, for a pilot. A variety of display types are being used. Some are full color, high resolution device with a wide field of view that tracks a pilot's head motions, providing a full viewing field and imbedded symbology for heads-up presentation of the operational and system information.

3) *Helmet Mounted Displays is a technology* that mounts various display hardware on a human head and projects images or information into one or both eyes of the user. HMDs are worn strapped or fitted to the user's head in the form of an enclosed helmet or eyeglasses. Images may be superimposed in the real world or the real world may be blocked allowing the user a fully immersed Virtual Reality world environment. In all designs, a head tracker is a necessity as an interface to the computer image generator that tracks and keeps up with the user's relative position, viewing angle and direction.

4) *Shutter glasses*: LCD screens or physically rotating shutters used to see stereoscopically when linked to the frame rate of a monitor.

5) *CRT (Cathode Ray Tubes)* - direct representation of scenes (as in TV), "blips" that represent objects (as in radar and aircraft-control-tower displays), graphic representations (as in various types of test and medical equipment), and generated alphanumeric and symbolic characters.

3. HMD Applications in Virtual Environments

Representative current HMD applications are:

1) Total Immersion of human subjects into the virtual environment, a la Virtual Reality

2) Necessary Hands-Free Operation

3) High Resolution Micro-displays

4) Combat Vehicle Crew (CVC) goggle with 1280 X 1024 active-matrix electroluminescent (AMEL) display for M1A2 tank commander.

5) Use of advanced sensor suites , ability to modify the visual scene presented.

4. LCDs and CRTs: A comparison overview

	LCDs	CRTs
RESOLUTION	(–) Poor 208 X 139 pixels	(+) Good 1200 - 1000 pixels
COLOR	(–) Poor	(+) Good
CONTRAST	(–) Low Ratios 5:1 to 20:1	(+) Good Ratios 100:1
Light (Weight)	(+)	(–)
Computer Update Rates	(–) Slow	(+)
Cheap/Wide Availability	(+)	(–)

5. Sample Achievements

Numerous research efforts conducted over the years suggest that the manner in which information is presented to the individual can radically improve or degrade the person's ability to understand and comprehend the significance of and act on the information. The benefits of this on-going research will be to improve understanding of the operational and training needs as well as display requirements for a variety of applications from aircrew operations to telepresence/telemedicine to dismounted soldier simulations. Here are a few highlighted programs.

1) Simulator Training Research Advanced Testbed for Aviation (STRATA), Ft Rucker, Alabama, May 1992 to Feb 1995. Experiment conducted using a pilot crew station and the stereoscopic fiber optic HMD in the simulation of the AH-64A helicopter. STRATA is a reconfigurable research testbed that can evaluate training subsystems for different aircraft types.

2) High Resolution Micro-displays

3) Combat Vehicle Crew (CVC) goggle with 1280 X 1024 active-matrix electroluminescent (AMEL) display for M1A2 tank commander.

4) Dismounted Soldier Simulation (DSS) , Veda Inc. and STRICOM Engineering Directorate.

6. Future Challenges

HMD systems are continually evolving and responding to current user demand including peripheral devices and software. Additional research is needed and there is a lack of established standards for viewing, dependent upon the user requirements. Research and development is required in the following areas to improve the utility of HMD systems and broaden the user base.

1) Higher level performance and lower power consumption for miniature display technologies for high-information-content capability.

2) Novel optics approaches for wide field-of-view displays in small, lightweight, form factors.

3) Reductions in display power consumption and electronics complexity in a wearable system.

4) Adapting new human interface techniques to the HMD information system.

5) Developing scaleable tools such as data compression techniques and image processors for matching information with the display.

6) Performing extreme integration of components and electronics.

7) HMDs used in Virtual Reality systems attempt to mimic the visual events of the real world, but they seem to come up short of expectations. These shortcomings can be the result of technological limitations that rotate, displace, differentially magnify, or differentially blur the images in the two eyes, or they can be the result of inviolate physical laws that cause the stereoscopic image to appear in a plane other than the plane of the LCD. These shortcomings adversely impact and overburden the human visual system, leading to information overload, fatigue, phobias, and simulation sickness.

8) Hardware and software issues arise depending upon the application. Design and use issues contribute to display weight, fit, cost, and dynamic cost and environment.

9) Hardware Issues: Selection of applicable display technology - CRT or Liquid Crystal. Field of View (FOV) matched to the task(s). CRTs have long been challenged by the problem of resolution, which is essentially the number of raster scan lines, or simply scan lines.

10) Stereoscopic disparities effects under dynamic viewing conditions; perceptual effects of shear and magnification (i.e., size) disparities under large-field stereoscopic viewing conditions.

7. Human Factors

1) Human performance in head mounted displays depends largely on the display's field of view (FOV). Light enters our eyes through an angular visual field that spans approximately 200 degrees horizontally and 150 degrees vertically, but this is not matched by typical head-mounted displays (HMD's).

2) Most of the surveyed HMDs have relatively narrow fields of view, ranging from roughly 30 to 70 degrees diagonally. Narrow FOV has been shown to degrade human performance on the following:

   a). Navigation

   b). Spatial Awareness

   c). Manipulation

   d). Target Tracking Tasks

   e). Disruption of eye-and-head -movement coordination

   f). Perception of size, space, and ego-center

   g). Psychological effects

3) Wide FOV displays are not yet generally available and if so, are only available at high-cost. Choosing the widest FOV available may not be optimal for many intended applications. Researchers have indicated that a wide FOV will aggravate simulator sickness effects, and in particular those due to vector and visual-vestibular mismatch, and may not be necessary for a task that is confined to a small space.

4) The last few years have seen the HMD reach acceptable standards for installation in the cockpit of military helicopters and fighters.

5) Adapting new human interface techniques to the HMD information system.

6) Performing extreme integration of components and electronics.

7) The use of any visual display such as the HMD depends upon the visual capabilities of the subject HMD user. The visual skills people have-especially visual acuity (resolution) and color discrimination (deficiency in the ability of the cones to differentiate various wave lengths) - have a direct bearing upon the design of visual

displays, particularly on the ability to detect relevant stimuli and to discriminate between and among variations thereof. The meaningfulness of what the subject sees in any visual display depends in part upon their perceptual processes and the learning of relevant associations. Thus the appropriate HMD design must be predicated in part upon the perceptual and learning factors as well as upon the specific visual skills of the user.

8) No available HMD provides a combination wide FOV and high resolution that matches the FOV and half-arc minute resolution of the human eye.

9) Trade-offs in FOV and resolution are necessary. Wide FOV is critical to applications where full virtual immersion is required and for tasks requiring peripheral vision. Human factors issues include but are limited to HDM weight, head supported weight, luminance, cost, and environment (temperature, shock, and humidity).

10) Further issues include human performance efficiency in virtual worlds, task characteristics, user characteristics, design constraints imposed by human sensory and motor physiology (visual, auditory, tactile, haptic). Also, integration issues with multi-modal interaction, virtual environment design metaphors, health and safety issues, cyber-sickness, and social impact.

11) HMDs tend to produce large distortions in the optics and lack of interpupillary adjustments either in the hardware or software. Future technology will evolve to correct these defects. Meanwhile, the headaches and discomfort of modern headmounts limit usage to a few hours a day at most.

8. Current/On-Going Research Efforts

Current applications include dismounted soldier simulation, ground vehicles tactics, techniques, and procedures, and rotary/fixed wing aircraft. The focus of these efforts include developing higher resolution (e.g. 5arc min/line pair), wider FOV (120 degrees ++), and lighter weight systems (< 4 lbs). Other technical issues being addressed include cross-systems compatibility, light weight for longer exposure. Significant on-going or completed Department of Defense research efforts are presented below.

The Joint Helmet-Mounted Cueing System (JHMCS)	Aeronautical Systems Center, Wright- Patterson AFB, Ohio.
Integrated Helmet Audio-Visual System (IHAVS) 3-D aural cueing, HMD for imagery and aircraft state information	Joint Advanced Strike Technology (JAST)
RAH-22 Comanche Helmet Integrated Display/Sight Subsystem (HIDSS) Heads up , eyes out pilotage capability that reduces pilot workload.	PM-Comanche, St. Louis, MO.
Helmet Mounted Mission Rehearsal Simulation System (HMMRSS) and other related projects Transportable flight simulation testbed to train deployed aircrews on high cost weapons systems and mission rehearsal tasks.	NAWCTSD, Orlando, FL.
Crew Station Technology Lab On-going projects in the last 9 years	NAWCAD, Pautuxent River, Md.
AL/HRA On-going projects in the last 12 years Night Vision Goggle using miniature CRTs; developed 5 different HMDs,	Armstrong Lab, Mesa, Arizona.
Simulator Training Research Advanced Testbed for Aviation (STRATA) Fiber Optic HMD in a reconfigurable rotary wing simulator	Ft Rucker, Alabama
Aerospace Vision Lab (AVL) Human visual performance assessment and the development of design recommendations for wide FOV, etc.	Armstrong Laboratory Crew Systems Directorate, Wright Patterson AFB, OH

Visual Perception in Synthetic Environments Program Behavioral research on visual perception.	Armstrong Laboratory, AL/HRAU, Mesa, Arizona
ARL/HRED Continued research to quantify deficits in human performance related to displays.	Army Research Laboratory, Human Research and Engineering Directorate, Aberdeen Proving Ground, Maryland.
Advanced Flat Panel Head Mounted Display Program (AFP) Development of a sterilizable, orthostereoscopic system	Honeywell Technology Center (HTC)
Full Immersion Head Mounted Display System Development of a range of full-peripheral vision head mounted display systems that high resolution, low-cost, and light-weight, based upon the Kaiser Electro-Optics (KEO) Visual Immersion Module (VIM) optical technology.	Kaiser Electro- Optics, Inc.
Virtual Environment Testbed Continual human-factors psychology experiments to evaluate the potential of Virtual Environment technology for use in training.	**Army Research Institute Environment Testbed and Institute for Simulation and Training (IST) University of Central Florida**
Combat Vehicle Crew- CVC HMD Program First high resolution (1280X1024) flat panel HMD. Designed for use by a M1A2 Abrams Main Battle Tank Commander, it shows IVIS (Inter-vehicular information system) information and thermal imagery from the commander's ITV (Independent Thermal Viewer)	Honeywell Technology Center DARPA HMD Program
DARPA HMD Program Seeks to develop and demonstrate miniature high definition flat panel displays and supporting technologies to enable a wide-range of mission critical, man-portable, and head-or-helmet-mountable functions (for virtual, augmented, and hybrid reality applications).	US Army Natick Research, Development, and Engineering Center, Medford, MA.

9. Bottom Line/Conclusion

HMD displays present complex scene content configurations. In the development and use of such displays, the dominant guideline is that of simplicity. Obviously, the application of this principle needs to be within the constraints imposed by the operational requirements for "fidelity" of the configuration. The argument for simplicity arises from the fact that the perceptual processes of "searching" for relevant features take longer (and are subject to high error rates) if an image is cluttered up with what may be irrelevant material.

One fundamental principle in deciding the right HMD is evaluating the issue of resolution using two important factors:

1. The net resolution of the internal display system (LCD or CRT)

2. The horizontally covered field of view or FOV. FOV values vary greatly for different HMDs. This is a result of a lack of standards in the manner of how a manufacturer presents these values. For this report, FOV values should always represent a 100% stereoscopic overlap configuration. Note that a user requires at least 20 degrees overlap to satisfy the human visual system.

With most display design challenges, one should first ask (and answer) the following questions: What information does the user need? and, How can that information best be presented? Obviously, the simplification of complex configurations should be guided by the answers to these questions.

10. HMD Manufacturers

HMDs continue to experience modest growth on the commercial market. As with typical technology trends, lower costs over time with proportionate increases in resolution will occur. Currently commercially-available low resolution HMDs cost under $10,000, with several baseline models under $1,000.The Table 1.0 below lists the current manufactures of helmet mounted display systems.

The following table is only a sampling of the representative manufacturers of HMDs. When examined closely, it is assumed that the analysis will reveal useful information about the HMD manufacturer population as a whole. The purpose of the sampling is to select and study a simple random number of HMD manufacturers

Note: The table does not rank, recommend, or rate each manufacturer or their product line.

Manufacturer	Contact	Product
3D-MAX	sales@ThreeD-Max.udac.se Tel: 46 (0)18187777 Fax: 46 (0) 18516600	3D-MAX Display: LCD shutter glasses
Astounding Technologies, Inc.	950 Benecia Avenue Sunnyvale, CA. 94086 USA Tel: (408) 522-0300 Fax: (408) 522-0310	Video Visor Display: Active Matrix LCD Resolution: 428 X 244 pixels Field of View: 30 (H) X 22.5 (V) Overlap: 100% Weight: < 14 oz.
CAE Electronics Ltd	8585 Cote de Liesse C.P. 1800 Saint-Laurent Quebec, Canada H4L4X4 Tel: (514) 341-6780 Fax: (514) 341-7669	Fiber-Optic HMD, Telepresence Visual System Display: CRT Resolution: pixel size 6.6 background, 2.2 inset; pixel structure: 1.2 million pixels distributed between inset and background Field of View: 120 degrees (H) X 55 degrees (V) Overlap: 25 degrees Weight: 4.5 lbs.
Division LTD	The Courtyard, #10 431 West Franklin Street Chapel Hill, NC 27516 Tel: (919) 968-7795 Fax: (919) 968-7890 E-Mail: info@division.com	dVISOR Display: Active Matrix Color LCD Resolution: 345 X 259 pixels Field of View: 105 (H) X 41 (V) Overlap: 40 degrees Weight: 80 oz.
Fakespace, Inc.	4085 Campbell Avenue Menlo Park, CA. 94025 Tel: (415) 688-1940 Fax: (415) 688-1949 E-Mail: fakespace@well.sf.ca.us WWW: www.fakespace.com	BOOM3M (mono) Display: dual CRT Resolution: 1280 X 1024 pixels Field of View: 104(H) X 90V) Tracking: 2DOF (pan and tilt), optomechanical

Forte Technologies, Inc.	1057 E. Henrietta Road Rochester, NY 14623 Tel: (716) 427-8595 Fax: (716) 292-6353 E-Mail: support@fortevr.com WWW: www.fortevr.com	VFX1 Display: Resolution: pixels Field of View: (H) X V) Tracking: (pan and tilt), optomechanical
General Reality Company	124 Race Street San Jose, CA 95126 Tel: (408) 289-8340 Fax: (408) 289-8258 E-Mail: sales@genreality.com WWW: www.genereality.com	
General Reality Company	124 Race Street San Jose, CA 95126 Tel: (408) 289-8340 Fax: (408) 289-8258 E-Mail: sales@genreality.com WWW: www.genereality.com	CyberEye CE-200N, CyberEye CEP-100 Display: dual active matrix LCD Resolution: 789 X 230 pixels Field of View: 22.5 (H) X 16.8 (V) Overlap: 100 % Weight: 14 oz.
General Reality Company	124 Race Street San Jose, CA 95126 Tel: (408) 289-8340 Fax: (408) 289-8258 E-Mail: sales@genreality.com WWW: www.genereality.com	ClearVue Display: monochrome CRT with LC filters Resolution: 1280 X 1024 pixels Field of View: 80 (H) X 40 (V) Overlap: 30 degrees Weight: 3 lbs, 5 oz.
Hughes Training. Inc	Link Division P.O. Box 1237 Binghamton, NY 13902-1237 Tel: (607) 721-4356 Fax: (607) 721-5600	CyberFace 2 Display: Single large format LCD, divergent axis Resolution: 385 X 119 pixels Field of View: 140 (H) X 110 (V) Overlap: 30 degrees Weight: 32 oz.
LEEP Systems	241 Crescent Street Waltham. MA 02154-3425 Tel: (617) 647-1395 Fax: (617) 899-9602	CyberFace 3 Display: Single large format LCD, head-coupled Resolution: 480 X 120 pixels Field of View: 80 (H) X 60 (H)
LEEP Systems	241 Crescent Street Waltham. MA 02154-3425 Tel: (617) 647-1395 Fax: (617) 899-9602	CyberFace 4 Display: Single large format LCD, head-coupled Resolution: 640 X 480 pixels Field of View: 80 (H) X 60 (H)
LEEP Systems	241 Crescent Street Waltham. MA 02154-3425 Tel: (617) 647-1395 Fax: (617) 899-9602	CyberFace 5 Display: Quad LCD, triple acuity Resolution: 1170 X 202 pixels FOV : 140 (H) X 110 (V)
LEEP Systems	241 Crescent Street Waltham. MA 02154-3425 Tel: (617) 647-1395 Fax: (617) 899-9602	MRG2/Mirage LCD Technology FOV: >110 degrees Resolution 240 X720

Liquid Image Corporation	659 Century Street Winnipeg, Manitoba R3H 0L9 Canada Tel: (204) 775-2633 Fax: (204) 772-0239 WWW: www.liquidimage.ca/vr	STV-01, Eyephone NewHRX
Nissho Electonics Corp	Advanced Electronics Systems Division 70301 Tsukiji, Chuo-ku Tokyo 104 Japan Tel: 81-3-3544-8452 Fax:81-3-3544-8284	Datavisor 9Ci and 10X Display: Dual CRT Resolution: 1280 X 1024 pixels Field of View: 50(H) X 37 (V) Weight: 3.5 lbs.
Nvision Inc.	7915 Jones Branch Drive Suite 1B10 McLean, VA 22102 Ph: (703) 506-8808 Fax: (703) 903-0455	

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"Human Factors Evaluation of Helmet Mounted Displays for Training Applications" 17th Interservice/Industry Training Systems and Education Conference (ITSEC 1995)	Christopher J. Whaley; Jeffery M. Gerth ;and Dennis J. Folds.
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